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Transverse Measurements of Polarization in Optically-Pumped Rb Vapor Cells

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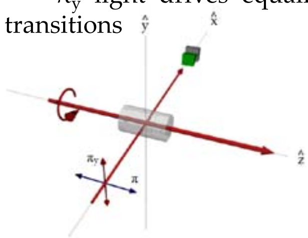
Polarization of optically-pumped alkali-metal vapors is typically determined by probing along the entire length of the pump beam resulting in an averaged value. Unfortunately, these measurements do not give information about spatial variations of polarization along the pump beam's propagation distance. Using a probe beam oriented perpendicular to the pump beam, we have demonstrated a heuristic method for measuring alkali-metal spin polarization.

Transverse Probe Beam: Linearly-polarized light normal to the z quantization axis can have two polarizations (Fig. 1):

--π light drives $\Delta m_f = 0$ transitions

--π_y light drives equally $\Delta m_f = +1$ and $\Delta m_f = -1$ transitions



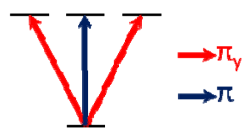


Fig. 1: A circularly-polarized beam pumps the Rb vapor. Transmission of perpendicular π and π_y linearly-polarized probe beams is measured.

Fig. 2: Sketch of possible transitions driven by transverse linearly-polarized light.

Probe Absorption in Maximally Polarized Vapor: (all atoms in $m_f = +F$)

$F_g > F_e$ (Fig. 3, left)

--π probe will not be absorbed

-- π_y probe will be absorbed

$F_g = F_e$ (Fig. 3, right)

--π probe will be absorbed

--π_y probe will be absorbed 50%

$F_g < F_e$

--no absorption difference

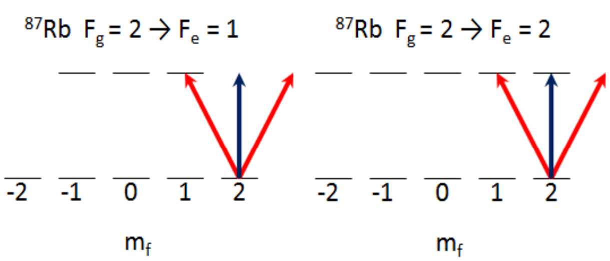


Fig. 3: Possible transitions from $F_g = 2$, $m_f = 2$ to $F_e = 1$ driven by transverse linearly-polarized light for left: ^{87}Rb $F_g = 2 \rightarrow F_e = 1$ and right: ^{87}Rb $F_g = 2 \rightarrow F_e = 2$.

Experimental Results: Absorption profiles obtained for π and π_y probe beams were subtracted to give a difference signal, *D*. The most prominent feature, referred to as D_{min}, corresponds to π_y more strongly absorbed than π near the ^{87}Rb $F_g = 2 \rightarrow F_e = 1$ transition.

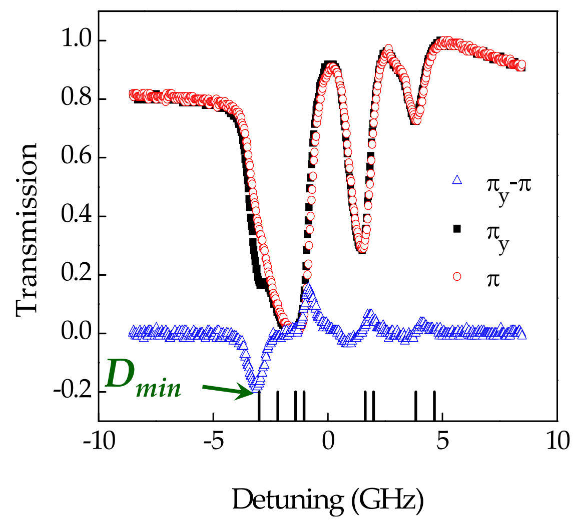


Fig. 4: Absorption profiles for π_y and π light and their difference (π_y - π) for Rb density of $2.4 \cdot 10^{12}$ cm^{-3} and 10 Torr N_2 buffer gas. The positions of hyperfine transitions are given at the bottom from left to right: ^{87}Rb $F_g = 2 \rightarrow F_e = 1$, ^{87}Rb 2 → 2, ^{85}Rb 3 → 2, ^{85}Rb 3 → 3, ^{85}Rb 2 → 2, ^{85}Rb 2 → 3, ^{87}Rb 1 → 1, ^{87}Rb 1 → 2.

Analysis: Data taken for seven Rb densities, *N*, each with 10 Torr of N_2 buffer gas, indicate an approximately linear relationship between D_{min} and P_{Rb} (Fig. 5). The non-zero intercept of lower densities is due to residual optical pumping by the probe beam alone. The applied longitudinal magnetic field maintains this alignment, causing the π_y and π probes to be absorbed differently.

Data was fit to the hyperbolic form

$$P_{Rb}(N, D_{min}) = -\sqrt{A(N)^2 + D_{min}^2 * B(N)^2} \tag{1}$$

If the *N*-dependence of the *A* and *B* fit-coefficients is found, the polarization of a Rb vapor of known density can be determined by simply measuring D_{min}.

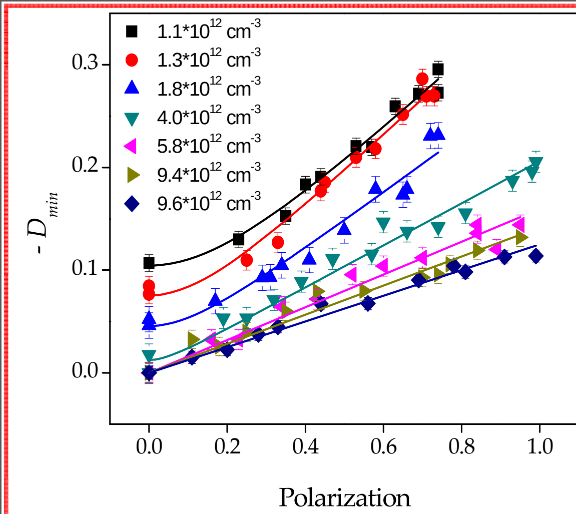


Fig. 5: D_{min} plotted versus longitudinal polarization measured by Faraday rotation [1]. A best fit line for each density yielded the fit coefficients A and B.

Modeling: A model is being developed to describe Fig. 5. Rate equations are different for π and π_y probe beams. For example, for the $m_F = +2$ state in ^{87}Rb $F_g = 2 \rightarrow F_e = 1$ transition, the probe contributions are

$$\frac{dn_{m_{F_g}=+2}}{dt} = k_{21}[0] \tag{2}$$

$$\frac{dn_{m_{F_g}=+2}}{dt} = k_{21}\left[\frac{1}{4}\left(n_{m_{F_e}=+1} - n_{m_{F_g}=+2}\right)\right], \tag{3}$$

where k_{21} is the laser induced transition rate ^{87}Rb $F_g = 2 \rightarrow F_e = 1$ transition. Terms in brackets show absorption strength. Other rates include spontaneous decay and spin-relaxation.

Potential Application: This method could be used to map spatial polarization variations of alkali-metal vapors. It has an advantage over traditional Faraday rotation in that it is relatively simple to set up.

References:

[1] H. Batelaan, A.S. Green, B.A. Hitt, and T.J. Gay, Phys. Rev. Lett. **82**, 4216 (1999).

[2] E.B. Norrgard, D. Tupa, J.M. Dreiling, and T.J. Gay, Phys. Rev. A **82**, 033408 (2010).

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